WHAT IS CLAIMED IS:

1. A method comprising:

confining ions to stable trajectories within an ion trap;

exciting a subset of the ions along at least one transverse coordinate;

rotating the transverse excitation into an excitation along an axial coordinate; and

transferring at least some of the axially excited ions from the ion trap along the axial coordinate.

2. The method of claim 1, wherein the confined ions have a mass-to-charge ratio within a specified range.

3. The method of claim 1, wherein the confining of the ions comprises generating electric fields within the ion trap.

4. The method of claim 3, wherein the electric fields are produced by a superposition of fields generated by multiple sets of electrodes.

5. The method of claim 3, wherein the electric fields produce linear dynamics for the ions in at least a central region of the ion trap.

6. The method of claim 5, wherein the electric fields generate a linear restoring force along the axial coordinate with respect to an origin in the central region of the ion trap.

7. The method of claim 5, wherein the electric fields generate a time-dependent restoring force of the form $p_r(t)r$ along each transverse coordinate with respect to an origin in the central region of the ion trap, where r denotes the transverse coordinate, t denotes time, and where $p_r(t)$ satisfies $p_r(t) = p_r(t+T)$ for some time interval T.

8. The method of claim 7, wherein the restoring force along each transverse coordinate is the same.

9. The method of claim 7, wherein the electric fields generate a linear restoring force along the axial coordinate with respect to an origin in the central region of the ion trap.

10. The method of claim 1, wherein the trajectory of each of the confined ions defines a frequency spectrum for each of the axial and transverse coordinates and each spectrum comprises at least one spectral peak at a frequency $\omega_{j,(m/Z)}$ that varies with the mass-to-charge ratio *m/Z* of the confined ion, where the index *j* denotes a particular one of the axial and transverse coordinates.

11. The method of claim 10, wherein $\left|\frac{\partial\omega_{r,(m/Z)}}{\partial(m/Z)}\right|$ is greater than $\left|\frac{\partial\omega_{z,(m/Z)}}{\partial(m/Z)}\right|$ for the subset of transversely excited ions, where the index *r* denotes either of the transverse coordinates and the index *z* denotes the axial coordinate.

12. The method of claim 11, wherein $\left|\frac{\partial\omega_{r,(m/Z)}}{\partial(m/Z)}\right|$ is greater than ten times $\left|\frac{\partial\omega_{z,(m/Z)}}{\partial(m/Z)}\right|$ for the subset of transversely excited ions.

13. The method of claim 1, wherein the exciting of the subset of ions comprises generating a time-dependent electric field along the transverse coordinate.

14. The method of claim 13, wherein the subset of ions comprises ions having a selected mass-to-charge ratio

15. The method of claim 14, wherein the time-dependent electric field resonantly excites the ions having the selected mass-to-charge ratio.

16. The method of claim 11, wherein the exciting of the subset of ions comprises generating an additional electric field along the transverse coordinate, wherein the additional

electric field is time-dependent and has spectral intensity at the transverse spectral peak frequency corresponding to a selected mass-to-charge ratio.

17. The method of claim 16, wherein the subset of ions comprises the ions having the selected mass-to-charge ratio.

18. The method of claim 1, wherein the rotating of the transverse excitation comprises generating an electric field that couples the transverse excitation to ion motion along the axial coordinate.

19. The method of claim 18, wherein the electric field that couples the transverse excitation to the ion motion along the axial coordinate corresponds to an electric potential in a central region of the ion trap, the electric potential comprising a spatial dependence of the form $(\alpha x+\beta y)z$ with respect to an origin in the central region, where α and β are constants, at least one of which is non-zero, x and y are the transverse coordinates, and z is the axial coordinate.

20. The method of claim 18, wherein the electric field comprises a frequency component equal to an absolute difference between a frequency of the transverse excitation and a frequency for axial motion in the ion trap for the transversely excited subset of ions.

21. The method of claim 18, wherein the electric field is maintained for a time sufficient to rotate the transverse excitation to the axial excitation.

22. The method of claim 11, wherein the rotating of the transverse excitation comprises generating an additional electric field that couples the transverse excitation to ion motion along the axial coordinate, wherein the additional electric field is time-dependent and has spectral intensity at a frequency equal to $\left|\omega_{r,(m/Z)}-\omega_{z,(m/Z)}\right|$ for a mass-to-charge ratio corresponding to at least some of the ions in the subset of transversely excited ions.

23. The method of claim 17, wherein the rotating of the transverse excitation comprises generating a second additional electric field that couples the transverse excitation to ion motion along the axial coordinate, wherein the second additional electric field is time-dependent and has spectral intensity at a frequency equal to $\left|\omega_{r,(m/Z)} - \omega_{z,(m/Z)}\right|$ for the selected mass-to-charge ratio.

24. The method of claim 23, wherein the first additional electric field terminates before the generation of the second additional electric field.

25. The method of claim 24, wherein the second additional electric field is maintained for a time sufficient to rotate the transverse excitation to the axial excitation.

26. The method of claim 1, wherein the transferred ions comprise ions having a selected mass-to-charge ratio.

27. The method of claim 1, wherein the transferring of at least some of the axially excited ions comprises lowering a gate potential at one end of the ion trap.

28. The method of claim 27, wherein the lowered gate potential prevents the confined ions other than the axially excited ions from escaping the ion trap through the one end.

29. The method of claim 25, wherein the transferring comprises lowering a gate potential at one end of the ion trap to transfer at least some of the axially excited ions having the selected mass-to-charge ratio and to not transfer other ions.

30. The method of claim 1, further comprising confining the transferred ions in a second ion trap.

31. The method of claim 30, further comprising fragmenting at least some of the ions confined in the second trap.

32. The method of claim 31, wherein the fragmenting comprises electromagnetically exciting the ions in the second trap.

33. The method of claim 29, further comprising confining the transferred ions in a second ion trap.

34. The method of claim 33, further comprising fragmenting at least some of the ions confined in the second trap.

35. The method of claim 1, wherein the ion trap is extended along the axial coordinate relative to the transverse coordinate.

36. An apparatus comprising:

a housing comprising a chamber for receiving ions and multiple electrodes surrounding the chamber, wherein the multiple electrodes define transverse and axial coordinates for ion motion within the chamber;

a set of power supplies coupled to the multiple electrodes; and

an electronic controller coupled to the set of power supplies, wherein during operation the electronic controller causes the set of power supplies to generate a series of electric fields in the chamber that: i) confines ions to stable trajectories within the chamber; ii) excites a subset of the ions along at least one of the transverse coordinates; iii) rotates the transverse excitation into an excitation along the axial coordinate; and iv) transfers at least some of the axially excited ions from the ion trap along the axial coordinate.

37. The apparatus of claim 36, wherein the power supplies comprise radio frequency (RF) and direct current (DC) sources for confining the ions to the stable trajectories.

38. The apparatus of claim 37, wherein the power supplies further comprise at least one alternating current (AC) source for exciting the subset of ions along the transverse coordinate and the rotating the transverse excitation to the axial excitation.

39. The apparatus of claim 38, wherein the electrodes coupled to the RF source are isolated from the electrodes coupled to any of the AC and DC sources.

40. The apparatus of claim 36, wherein during operation the electronic controller causes the electrodes surrounding the chamber to define a harmonic linear trap.

41. The apparatus of claim 36, wherein the housing is extended along the axial coordinate relative to the transverse coordinate.

42. An apparatus comprising:

a housing comprising a chamber for receiving ions and multiple electrodes surrounding the chamber, wherein the multiple electrodes define transverse and axial coordinates for ion motion within the chamber;

a set of power supplies coupled to the multiple electrodes; and

a electronic controller coupled to the set of power supplies, wherein during operation the electronic controller is configured to cause the set of power supplies to generate a time-dependent electric field along at least one of the transverse coordinates, and further configured to cause the set of power supplies to generate a time-dependent electric field that couples the axial coordinate to the transverse coordinate.

43. The apparatus of claim 41, wherein the set power supplies are configured to generate the transverse time-dependent electric field at a first frequency selected by the electronic controller and generate the coupling time-dependent electric field at a second frequency selected by the electronic controller.

44. The apparatus of claim 42, wherein the electric field that couples the transverse excitation to the axial coordinate corresponds to an electric potential in a central region of the chamber, the electric potential comprising a spatial dependence of the form $(\alpha x + \beta y)z$ with respect to an origin in the central region, where α and β are constants, at least one of which is non-zero, x and y are the transverse coordinates, and z is the axial coordinate.

45. The apparatus of claim 42, wherein the housing is extended along the axial coordinate relative to the transverse coordinate.

46. The apparatus of claim 42, wherein electronic controller is further configured to cause the power supplies to generate electric fields in the chamber that define a harmonic linear trap.

47. A method comprising:

generating an axially extended RF trapping field to transversely confine ions;

providing a spatially localized modification in the extended RF trapping field, wherein the modification imparts an axial force on incident ions that varies with a mass-to-charge ratio of each incident ion; and

directing ions from a first trapping region to the spatially localized modification to allow some of the ions from the first trapping region to penetrate though the spatially localized modification and not others.

48. The method of claim 47, wherein the directing of the ions comprises imparting kinetic energy to the ions in the direction of the spatially localized modification.

49. The method of claim 48, wherein imparting the kinetic energy comprises adjusting DC potentials between the first trapping region and the spatially localized modification.

50. The method of claim 47, wherein the first ion trapping region is a linear ion trap (LIT).

51. The method of claim 47, further comprising:

confining the ions that penetrate through the spatially localized modification in a second ion trapping region adjacent the spatially localized modification.

52. The method of claim 51, wherein the first and second ion trapping regions are linear ion traps that are axially aligned with one another.

53. The method of claim 47, wherein the axial force increases as the mass-to-charge ratio decreases.

54. The method of claim 53, wherein the ions that penetrate through the spatially localized modification have a mass-to-charge ratio above a threshold value.

55. The method of claim 51, further comprising:

directing the ions in the second ion trapping regio back to the spatially localized modification to allow some of the ions from the second ion trapping region to penetrate through the it and others of the ions to reflect from it and remain confined in the second ion trapping region.

56. The method of claim 55, wherein the directing of the ions from the first trapping region to the spatially localized modification comprises imparting a first amount of kinetic energy to the ions in the direction of the spatially localized modification and wherein the directing of the ions from the second trapping region to the spatially localized modification comprises imparting a second amount of kinetic energy to the ions in the direction of the spatially localized modification.

57. The method of claim 56, wherein the first and second amounts differ.

58. The method of claim 56, further comprising adjusting the strength of the axial force prior to directing the ions in the second trapping region back to the first trapping region.

59. The method of claim 56, wherein the first amount of kinetic energy causes ions having a mass-to-charge ratio above a first threshold to penetrate through the spatially localized modification, the second amount of kinetic energy causes ions having a mass-to-

charge ratio above a second threshold greater than the first threshold to penetrate through the spatially localized modification, and the ions remaining in the second ion trap have mass-to-charge ratios between the first and second thresholds.

60. The method of claim 47, wherein providing the spatially localized modification comprises applying an RF potential to electrodes on at least opposite sides of the spatially localized modification.

61. The method of claim 60, wherein providing the spatially localized modification further comprises applying an RF potential to additional electrodes surrounding regions extending transversely from the spatially localized modification relative to an axis defined by the first ion trapping region.

62. The method of claim 47, wherein providing the spatially localized modification comprises providing holes in axially extended electrodes used to generate the RF trapping field.

63. The method of claim 47, wherein providing the spatially localized modification comprises providing deformations in axially extended electrodes used to generate the RF trapping field.

64. The method of claim 63, wherein the deformations extend inwardly toward the RF trapping field.

65. An apparatus comprising:

electrodes configured to produce an axially extended RF trapping field that transversely confines ions, wherein the electrodes are modified to produce a spatially localized region in the axially extended RF trapping field that imparts an axial force on incident ions that varies with a mass-to-charge ratio of each incident ion;

a set of power supplies including at least direct current (DC) and RF power supplies coupled to the electrodes; and

an electronic controller coupled to the set of power supplies, wherein during operation the electronic controller causes the set of power supplies to: i) generate the axially extended RF trapping field and the spatially localized region in the axially extended RF trapping field; and ii) direct ions from a first trapping region to the spatially localized region to allow some of the ions from the first trapping region to penetrate though the spatially localized region and not others.

66. A method comprising:

generating an axially extended RF trapping field to transversely confine ions;

providing a spatially localized modification in the extended RF trapping field, wherein the modification imparts an axial force on incident ions that varies with a transverse displacement of each incident ion;

increasing a transverse oscillation amplitude of a subset of the ions from a first ion trapping region, wherein the subset of ions comprises ions having a selected mass-to-charge ratio; and

directing the ions toward the spatially localized modification to cause some of the ions to penetrate through it and not others.

67. The method of claim 66, wherein the magnitude of the axial force decreases with the transverse displacement of the incident ions, and wherein the ions that penetrate through the spatially localized modification comprise the subset of ions whose transverse oscillation amplitude was increased.

68. The method of claim 66, wherein the magnitude of the axial force increases with the transverse displacement of the incident ions, wherein the ions that do not penetrate through the spatially localized modification comprise the subset of ions whose transverse oscillation amplitude was increased.

69. The method of claim 66, wherein the first ion trap is a linear ion trap (LIT).

70. The method of claim 66, wherein the increasing of the transverse oscillation amplitude of a subset of the ions comprises generating time-varying electric field along at least one of the transverse coordinates, wherein the time-varying electric field has spectral intensity at a frequency corresponding to the stable trajectory of the ions having the selected mass-to-charge ratio along the transverse coordinate.

71. The method of claim 66, wherein the directing of the ions comprises imparting kinetic energy to the confined ions in the direction of the spatially localized modification.

72. The method of claim 71, wherein imparting the kinetic energy comprises lowering a gate potential between a first ion trapping region and the spatially localized modification.

73. The method of claim 66, further comprising:

confining the ions that penetrated through the spatially localized modification in a second ion trapping region adjacent the spatially localized modification.

74. The method of claim 73, wherein the first and second ion trapping regions are linear ion traps that are axially aligned with one another.

75. The method of claim 66, wherein generating the spatially localized modification comprises applying an RF potential to electrodes on at least opposite sides of the spatially localized modification.

76. The method of claim 75, wherein generating the spatially localized modification further comprises applying an RF potential to additional electrodes surrounding regions extending transversely from the spatially localized modification relative to an axis defined by the first ion trapping region.

77. The method of claim 66, wherein providing the spatially localized modification comprises providing holes in axially extended electrodes used to generate the RF trapping field.

78. The method of claim 66, wherein providing the spatially localized modification comprises providing deformations in axially extended electrodes used to generate the RF trapping field.

79. The method of claim 78, wherein the deformations extend inwardly toward the RF trapping field.

80. An apparatus comprising:

electrodes configured to produce an axially extended RF trapping field that transversely confines ions, wherein the electrodes are modified to produce a spatially localized region in the axially extended RF trapping field that imparts an axial force on incident ions that varies with a transverse displacement of each incident ion;

a set of power supplies including at least direct current (DC) and RF power supplies coupled to the electrodes; and

an electronic controller coupled to the set of power supplies, wherein during operation the electronic controller causes the set of power supplies to: i) generate the axially extended RF trapping field and the spatially localized region in the axially extended RF trapping field; ii) increase a transverse oscillation amplitude of a subset of the ions from a first ion trapping region, wherein the subset of ions comprises ions having a selected mass-to-charge ratio; and iii) direct the ions toward the spatially localized modification to cause some of the ions to penetrate through it and not others.

81. An apparatus comprising:

electrodes configured to produce an axially extended RF trapping field that transversely confines ions, wherein the electrodes are modified to produce a spatially localized region within the axially extended RF trapping field that imparts an axial force on

incident ions, wherein the axial force varies with a mass-to-charge ratio of each incident ion; and

a set of power supplies including at least direct current (DC) and RF power supplies coupled to the electrodes.

82. The apparatus of claim 81, wherein the axial force also varies with a transverse displacment of each incident ion

83. The apparatus of claim 81, wherein the electrodes further define first and second ion trapping regions on opposite sides of the spatially localized modifications, wherein the first and second trapping regions are linear ion traps (LITs).

84. The apparatus of claim 81, wherein the spatially localized modification comprises electrodes on at least opposite sides of the spatially localized modification and additional electrodes surrounding regions extending transversely from the spatially localized modification relative to an axis defined by the axially extended RF trapping field.

85. The apparatus of claim 81, wherein the spatially localized modification comprises holes in axially extended electrodes used to generate the RF trapping field.

86. The apparatus of claim 81, wherein the spatially localized modification comprises deformations in axially extended electrodes used to generate the RF trapping field.

87. The apparatus of claim 86, wherein the deformations extend inwardly toward the RF trapping field.